NAS 8-2696-TM-00069

TECHNICAL MEMORANDUM

1. Allis-Chalmers Mfg. Co., Milwaukee, Wis. 3 9 November 30, 1964 10

To: R. W. Kelm

From: 6 P. D. Hess 9

Subject: 3 Water Recovery Subsystem, Development Plan, 6 Activity 170

Distribution: J. L. Platner, D. [illegible] Ghere, R. E. Lochen, J. R. Hurley, J. E. Ward, C. R. Martin, G. Johnson

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1. Assignment

The individual to whom this memorandum is directed is assigned the design effort responsibility of evolving the initial design, feasibility test specification, design specification, drawings, and/or functional diagrams of the subject subsystem (Activity 170 - 435). A concerted attempt should be made to meet all dates set forth in the Part III PERT Program Plan.

2. Function

The Water Recovery Subsystem (WRS) will modify the Fuel Cell Power Supply System to the closed loop design. It will receive the product water from the Fuel Cell Assembly in the vapor state and will provide for recovery, accumulation, storage and release of this product as potable water for consumption. The WRS consists of a condenser subassembly, a water storage subassembly and a control subassembly.

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The condenser subassembly accepts water vapor from the moisture removal subsystem where it is condensed and by diffusion passed through an asbestos membrane to the storage subsystem. Vehicle coolant is used to cool the condensing surface. Small amounts of hydrogen are carried with the water vapor to the condenser where it becomes trapped along the condensing surface. Therefore, a means of purging may be necessary.

The recovered water is transported to the storage subassembly where it is first accumulated in a tank. Here the pH value of the water is monitored to be sure that KOH has not been transported through the condenser and contaminated the water. If it is contaminated (pH $>$ 9.0) the water can be dumped to space. If it is pure, the water is transferred under pressure into a storage tank for use. The water in the storage tank is always under a pressure greater than the cabin pressure so that water can be drawn off without pumping.

The control subassembly regulates the water pressure in the accumulator tank so that a pressure differential always exists between the condenser and accumulator, to cause flow. It also provides the pressurized gas to pump the accumulated water to the storage tank or to space if the water is contaminated. The electrical system shown in Figure 2 will also be included as part of the control subassembly. If it becomes necessary, controls for periodic purging of hydrogen from the condenser can be added.

3. Status

The initial feasibility design of the condenser uses a cooled plate (similar in shape to a fuel cell plate) above a membrane which is made up of a 0.03" sheet of asbestos with a support plaque on each side. Water is condensed on the cooled plate and flows to the membrane due to the high capillary potential of the membrane. The water flows through the membrane into water removal passages, and then into an accumulator due to a pressure difference of approximately 0.5 psi. A vent is supplied in the water vapor grooves to vent hydrogen to space, if needed. Sub-cooling of the water is obtained by conduction of heat from the condensed water to the cooled plate. Components of the condenser are being fabricated in our own shops, see Drawing 49-200-201.

The preliminary design of the water storage subassembly will be a one liter ellipsoidal tank for both the accumulator and storage tanks with butyl rubber bladders. The ellipsoidal shape was selected to minimize the movement of the bladder. The bladder in the accumulator is intended to form the contour of the tank both in the full position and the empty position. This minimizes the external volume of the tank and the amount of oxygen required to empty the tank. An ampere-hour meter will signal when the accumulator is full, and a microswitch on the top of the tank will signal when the tank is empty. A microswitch cannot be used to indicate when the tank is full because in the filling operation the pressure difference across the bladder is too small to operate a switch. However, using an ampere-hour meter means that the accumulator cannot be completely filled. A sufficient safety factor (20%) must be allowed so that overflow cannot occur. Therefore, the accumulator will be emptied when approximately 0.8 liter of water would normally be admitted. The filling time of the accumulator is approximately one hour at full load. The accumulator will be emptied within one minute or less.

The storage tank is similar in shape to the accumulator except that the lower half is larger by approximately 0.4 liter. The storage tank is essentially an accumulator with a fixed mass of gas contained within a flexible bladder. Thus the maximum volume of water contained within the bladder is one liter and the volume of gas outside the bladder is a minimum of 0.4 liter.

As water is pumped from the accumulator, the pressure within the storage tank increases. The storage tank is filled when the pressure reaches a maximum of 35 psia. At this pressure, a relief valve opens and any excess water in the accumulator is vented to space. The minimum pressure in the storage tank will be 10 psia when the tank is empty. The volume of water in the tank can be determined from a pressure transducer which has been calibrated in proportional parts of a full tank for pressures from 10 psia (empty) to 35 psia (full). Thus, a half-full tank would correspond to a pressure of 22.5 psia on transducer, etc. Drawings of the accumulator and storage tank are being made for fabrication in our shops. See Drawing 49-400-125 and 49-400-126 respectively.

Figure 1 is a schematic drawing of the Water Recovery Subsystem showing the valves and other related equipment required. It is anticipated that all of these will be commercially available for the first feasibility test unit.

The function and requirements of the major valves are listed below.

<u>Valve "A" - Coolant Control</u>

Function	-	Regulate coolant flow rate to maintain constant pressure in condenser
Media	-	60% Methanol, 40% Water at 60° F
Flow	-	100 pounds per hour
Type	-	Two-way solenoid operated Latched 30 volts, d.c.
Inlet pressure	-	35 psia
Pressure drop	-	3 psia

<u>Valve "B" - Water Vapor Control</u>

Function	-	Switch water vapor from WRS to space
Type	-	Three way solenoid operated Latched 30 volts, d.c.

Media	-	Water vapor and trace of KOH at 195° F
Flow	-	2.5 pounds per hour
Pressure	-	2 to 11.0 psia
Back pressure	-	To space - 0.5 psia Latched Open To WRS - 2.5 psia Normally Open

May be part of the Moisture Removal Subsystem in the final design.

Valve "C" - Water Vapor Relief

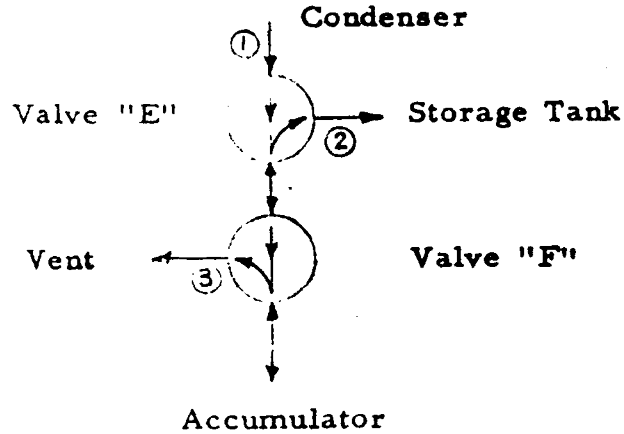
Function	-	Prevent high back pressure on fuel cell
Type	-	Relief - Mechanical
Media	-	Water vapor and trace of KOH at 195° F
Flow	-	2.5 pounds per hour
Cracking pressure	-	2.5 psia
Maximum pressure	-	11.0 psia
Outlet pressure	-	0.5 psia

Valves "E" and "F" - Water Control Valves

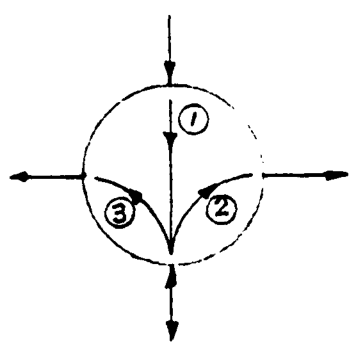
Function	-	Pass water from condenser to accumulator 1 and pass water from accumulator to storage tank 2 or to space 3 .
Type	-	Three-way solenoid operated valve (see alternative following)
Coil	-	30 volts, d.c., intermittent duty (1 minute per hour)
Media	-	Water at 110° F plus trace of KOH

Valves "E" and "F" - (Continued)

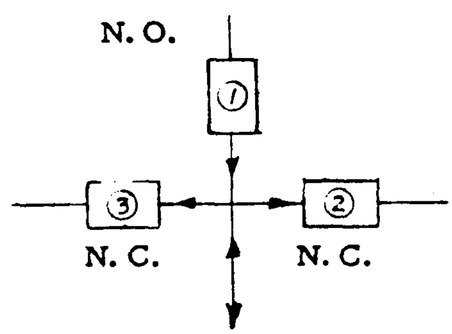
Path	1	2	3
Flow (gallons per minute)	.005 (max)	.3 (max)	.3 (max)
Inlet pressure (psia)	2 (min)	45 (max)	45 (max)
Outlet pressure (psia)	1.8 (min)	40 (max)	0.5 (max)
Valve energized	none	"E"	"F"



As an alternative, one four-way valve with two coils may be used if internal leakage is not excessive and if it can be made corrosion resistant. Both the three-way and four-way valves are subjected to reversed flows. If this is not feasible, three two-way valves could be used, but this increases the weight, volume and power requirements.



Four-way Valve



Two-way Valve

Valve "K" - Oxygen Control Valve

Type - Three-way solenoid operated valve *

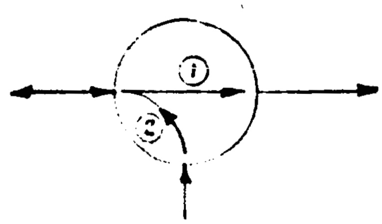
Coil - 30 volts, d. c. intermittent duty (1 minute per hour)

Media - Oxygen at 75° F nominal temperature, range 0 - 150° F

Flow - Path 1 - Allow 1 liter tank at 40 psia maximum to be lowered to 1.8 psia in 30 seconds. Back pressure - 0.5 psia.

Path 2 Build up pressure in 1 liter tank from approximately 1.8 psia to 40 psi maximum in one minute from a 45 psi source.

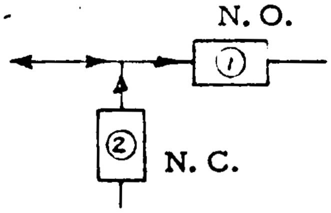
Accumulator



Vent

Oxygen Source, 45 psia

* If reverse flow is not allowed, use two two-way valves, but this increases weight, volume and power requirements.



Two-way Valve

Valve "G" - Prevent water flow from storage tank to accumulator

Type - Check valve

Media - Water at 110° F plus trace of KOH

Flow - Pass 1 liter in one minute

Valve "G" - (Continued)

Cracking pressure difference	-	5 psi maximum
Inlet pressure	-	45 psia maximum

Valve "J" - Storage Tank Relief Valve

Type	-	Relief Valve
Media	-	Water at 110° F plus trace of KOH
Flow	-	Pass 1 liter in one minute maximum
Inlet pressure	-	45 psia maximum
Cracking pressure	-	35 psia
Back pressure	-	0.5 psia

Valve "L" - Accumulator Vacuum Regulator

Type	-	Regulator, Mechanical
Media	-	Oxygen at 75° F nominal, range 0 - 150° F
Flow	-	Relieve pressure in 1 liter tank from 45 psia to 1.8 psia in 30 seconds.
Outlet pressure	-	0.5 psia

Maintain a set pressure of 1.8 psia within $\pm$0.1 psia

Valve "M" - Oxygen Regulator

Type	-	Regulator, Mechanical
Media	-	Oxygen at 75° F nominal, range 0 - 150° F
Flow	-	Pass enough oxygen to raise 1 liter tank from 1.8 psia to 45 psia (maximum) in 1 minute
Inlet pressure	-	300 psia
Outlet pressure	-	45 psia

The operation of the WRS as shown in Figure 1 is outlined as follows. The water vapor from the WRS of the fuel cell passes through a three-way valve "B" which directs the flow to either the WRS or to space. Thus, if the WRS is not functioning properly the water vapor can be dumped directly to space. Relief valve "C" prevents a high back pressure on the WRS due to flooding the condenser or due to a build-up of hydrogen in the condenser. The water vapor or hydrogen can be vented through the valve. Coolant control valve "A" by-passes sufficient coolant to the discharge line to maintain a constant pressure on the condenser. The valve is a latched solenoid valve receiving its signal from a controller using a pressure transducer.

The water vapor passes into the condenser where it is condensed and sub-cooled. The condensed water passes through two three-way solenoid valves, "E" and "F", into the accumulator when the electrical system is de-energized (see Figure 2). The pressure in the accumulator tends to build-up and the pressure relief valve "L" bleeds off oxygen to maintain the fixed accumulator pressure of 1.8 psia. The three-way solenoid valve "K" is open to vent. During the filling operation a pH sensor continuously monitors the water in the accumulator and if the value exceeds the limits, 7.0 to 9.0, a manual signal can be given to dump the water to space. The electrical circuit energizes valve "F" which opens the accumulator to space and isolates it from the condenser, and energizes valve "K" which admits pressurized oxygen to decrease the time required to empty the accumulator. The microswitch on top of the accumulator signals when the accumulator is empty and de-energizes the system to start the filling cycle again. The stop button can be used to stop the dump at any time.

When the accumulator is full, valve "E" is energized to admit water to the storage tank and valve "K" is energized to admit pressurized oxygen to force the water into the storage tank through a de-ionizer and a check valve "G". The check valve prevents flow back into the accumulator when the oxygen pressure is removed. If the storage tank is filled (storage tank pressure of 35 psia) before all the water is transferred, the relief valve "J" dumps the excess to space. Water can be drawn off by opening valve "H".

4. Development Areas

The major components of the Water Recovery Subsystem (condenser, accumulator, and storage tank) have been designed. These units will be fabricated and tested.

The condenser design has been patterned after a fuel cell to make the preliminary unit simple to fabricate. The heat transfer area between the coolant and the cooled plate is the limiting factor in this design and probably in all possible designs. The limitation of 100 pounds per hour of coolant, and $<$ 5 psi pressure drop make the flow in the coolant channels laminar (RE = 300) and therefore produces lower heat transfer coefficients. Therefore, a development program, to increase the heat transfer coefficient or increase the heat transfer area is necessary. Other designs which would increase the heat transfer coefficient will be attempted.

No positive means of sub-cooling the condensate has been provided. If heat transfer through the plate does not sub-cool the liquid, a small heat exchanger can be installed after the condenser to provide this function.

We do not have any experience with the water storage subassembly and the control subassembly, therefore, all phases of these assemblies will require extensive development. The preliminary assemblies will be built and tested and any necessary modifications made.

The following areas will require study:

(1) With the one liter storage tank the water must be removed to provide room for the accumulated water. The one liter size was selected to make the initial design simple to fabricate because it is the same size as the accumulator. Therefore, in the final design the storage tank should be larger. The size will have to be determined.

(2) Allowable pressure drop limits through solenoid valves "E" and "F" will have to be determined as they may limit the minimum KOH cavity pressure, if the pressure drops are significant and cannot be avoided.

(3) The oxygen supply for forcing the water from the accumulator is obtained from a separately regulated supply of reactant oxygen. It may be possible to eliminate this regulator if oxygen can be taken from the regulated supply of reactant oxygen which is approximately 37 psia.

(4) Some of the solenoid valves, such as valves "B", "E", "F", and "K", will require investigation to determine which type to use. They are all shown as three-way valves, but two-way valves may be necessary in some cases.

(5) Valve "A" should be investigated to determine if a mechanical pressure-controlled, proportioning valve could be substituted for the solenoid valve and controller.

5. Test Plan

Preliminary testing should be done on the individual components, where possible, to determine the feasibility of their designs.

The condenser should be tested using steam as the media with hydrogen introduced to determine the effect of non-condensable gases on the condenser efficiency.

The water storage subassembly should be tested as a unit after components have been checked out.

When all subassemblies have been tested, the complete integrated subsystem should be tested using the output of the 2000 watt fuel cell, whose pH readings are naturally low enough to observe the functioning of the entire subsystem. Parasitic load draw as a function of time should be continuously recorded as well as other parameters designated.

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Engineering Section

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Attachments - Figures 1 and 2

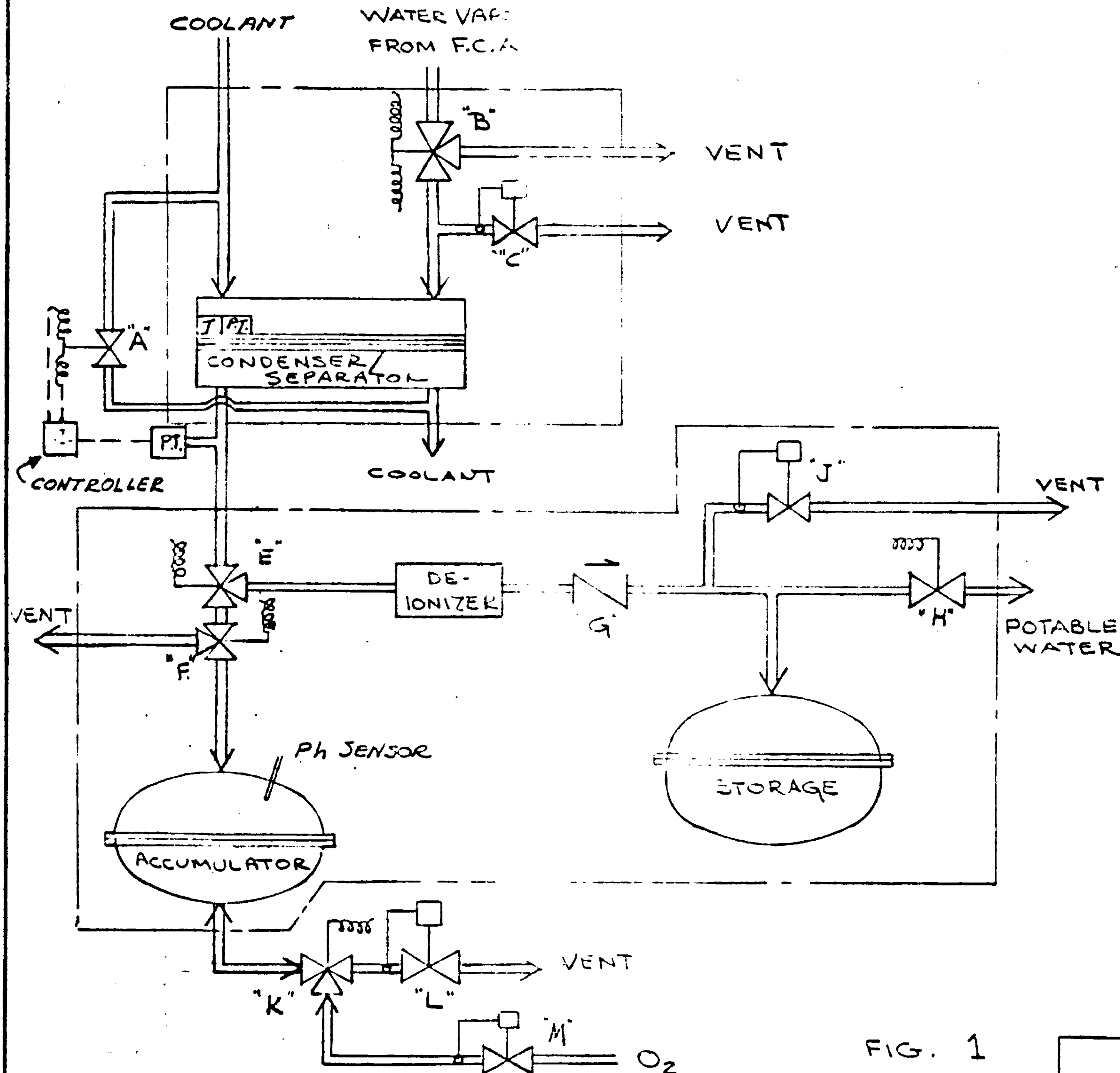
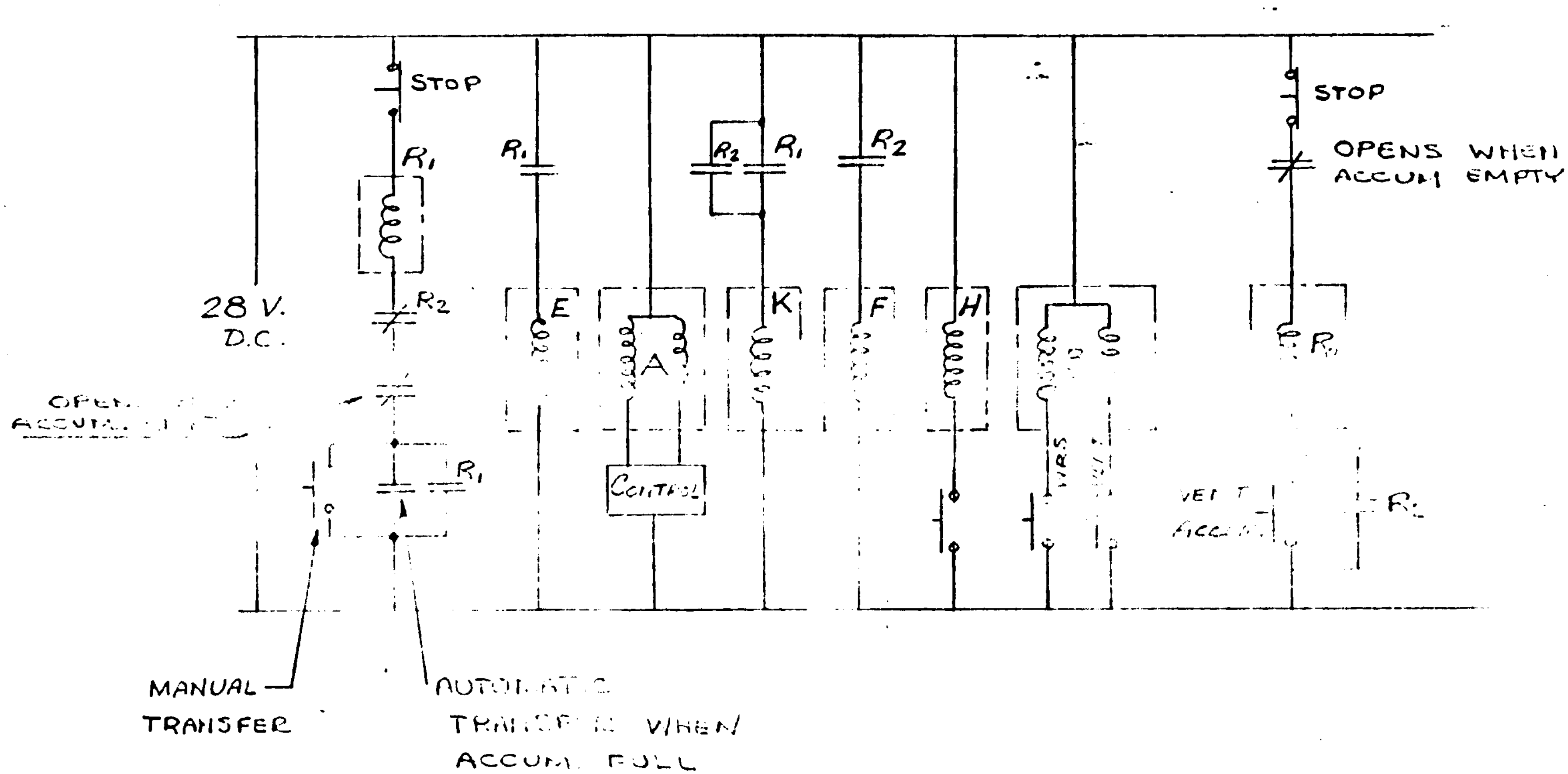


FIG. 1

SCHEMATIC
WATER RECOVERY
SUB-SYSTEM

DR'N R.W.K. 9-30-64	CH'D	APP'D	SCALE — =12	SIMILAR TO
Confidential—Property of ALLIS-CHALMERS MFG. CO.	DEPT. RESEARCH			SHEET OF / ISSUE

WATER RECOVERY SUBSYSTEM WIRING DIAGRAM



NOTE: WHEN SYSTEM DE-ENERGIZED - SUBSYSTEM ACCUMULATING WATER.

FIG. 2